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THESIS

SURFACE COMBATANT INTEGRATION OF METOC DATA ACQUISITION AND PRODUCT DISTRIBUTION SYSTEMS WITHIN THE IT-21 COMMUNICATIONS ARCHITECTURE

by

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SURFACE COMBATANT INTEGRATION OF METOC DATA ACQUISITION AND PRODUCT DISTRIBUTION SYSTEMS WITHIN THE IT-21 COMMUNICATIONS ARCHITECTURE

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ABSTRACT

In an at-sea demonstration, a prototype shipboard environmental observing system and a meteorological and oceanographic (METOC) data distribution software package are combined with the Automated Digital Network System (ADNS) to highlight the benefits of instituting an integrated data collection and distribution suite to ships, battlespace managers, and the METOC community. Limitations of traditional METOC support, inaccuracies and inherent deficiencies of shipboard observations, and current U. S. Navy weather observing policies are discussed and recommendations are proposed to improve the timeliness, accuracy, and archival of METOC information. A conceptual model for METOC support to and from surface combatants using advanced sensors, innovative software, and IT-21 communications is presented.

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LIST OF ACRONYMS

ADNS	Automated Digital Network System
AG	Aerographers Mate
AREPS	Advanced Refractive Effects Prediction System
BMDA3	Battlespace METOC Data Acquisition, Assimilation and Application
CAP	Channel Access Protocol
CNMOC	Commander, Naval Meteorology and Oceanography Command
COAMPS	Coupled Ocean/Atmosphere Mesoscale Prediction System
COE	Common Operating Environment
COTS	Commercial-Off-The-Shelf
DAMA	Demand Assigned Multiple Access
DII	Defense Information Infrastructure
DOD	Department of Defense
DON	Department of the Navy
DWTS	Defense Wideband Transmission System
EHF	Extremely High Frequency
EOTDA	Electro-Optical Tactical Decision Aid
ERM	Electronic Records Management
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FTP	File Transfer Protocol
GBS	Global Broadcast System
GOTS	Government-Off-The-Shelf
HF	High Frequency
HSD	High Speed Data
HTTP	Hypertext Transfer Protocol
INM	Integrated Network Management
INMARSAT	International Maritime Satellite
IP	Internet Protocol
IT-21	Information Technology for the 21st Century
JMCIS	Joint Maritime Command Information System
JMCOMS	Joint Maritime Communication System
JMV	Joint METOC Viewer

LAN	Local Area Network
MET	Mobile Environmental Team
METOC	Meteorology and Oceanography
MIME	Multipurpose Internet Mail Extension
NAVAIR	Naval Air Systems Command
NC	Network Centric
NES	Network Encryption System
NII	National Information Infrastructure
NIPRNET	Non-secure IP (Internet Protocol) Router Network
NITES	Navy Integrated Tactical Environmental System
NOC	Network Operating Center
OSPF	Open Shortest Path First
OTSR	Optimum Track Ship Routing
PKI	Public Key Infrastructure
PRNOC	Pacific Region Network Operating Center
QMEL	Quartermaster Environmental Log
R&S	Routing and Switching
REA	Rapid Environmental Assessment
SATCOM	Satellite Communications
SCIMS	Surface Combatant In Situ METOC Sensor
SHF	Super High Frequency
SIPRNET	Secret IP (Internet Protocol) Router Network
SNMP	Simple Network Management Protocol
SOCAL	Southern California
SPAWAR	Space and Naval Warfare Systems Command
TDA	Tactical Decision Aid
TEDS	Tactical Environmental Data Server
UHF	Ultra High Frequency
VPN	Virtual Private Network
VLSTRACK	Vapor, Liquid, and Solid Tracking Model
WAN	Wide Area Network
WMO	World Meteorological Organization

WWW	World Wide Web
XML	Extended Markup Language

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CSC—Mr. Brian Frew
PRNOC—Mr. Dennis Chang

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I. INTRODUCTION

Meteorological and oceanographic (METOC) data acquisition and product distribution for surface combatants has remained unchanged for a number of years. As naval warfare has shifted its focus from the open ocean into littoral regions, where temporal and spatial changes in atmospheric and oceanographic characteristics can significantly affect the tactical ability of the ship's weapon systems, requirements for timely and accurate environmental information have rapidly increased. Wind shifts with a frontal passage, onset of a land-sea breeze, evaporation duct height changes, and increased wave heights are but a few examples of environmental changes that can dramatically affect weapon system performance. Operational METOC commands have made significant strides towards meeting these requirements with advanced coupled mesoscale forecast models, improved tactical decision aids, and tailored environmental products. However, use of this improved support has not been easily attainable by surface combatants because of limited access to communications resources.

A limiting factor to providing enhanced METOC support seems to have been the capacity and characteristics of available communication paths. Surface combatants have not generally been equipped with communications suites that support network topologies and the transfer of large data sets, such as satellite imagery and value-added METOC products. Current fleet deployment of the Automated Digital Network System (ADNS) offers a solution to this problem by providing a common, adaptable framework for standard Internet Protocol (IP) network communications to surface combatants.

A second limiting factor appears to be the human error involved in existing observational procedures. Synoptic reporting by shipboard personnel has frequently been shown fraught with error. Lack of training, poor attention to detail, and inadequate or malfunctioning sensors result in synoptic observations that do not accurately describe the environment. In oceanic regions, where data are sparse, this is unacceptable. Program development of Moriah, a new suite of shipboard sensors, promises to greatly improve both the quality and quantity of information provided by surface ships.

In this study, a prototype Moriah system is coupled with ADNS and Fleet Numerical Meteorology and Oceanography Center (FNMOC) METCAST distribution software aboard USS Juneau (LPD-10). This was accomplished during USS Juneau's participation in Littoral Lightning, a segment of Fleet Battle Experiment Echo, in the Southern California (SOCAL) operating area in April 1999.

Shipboard environmental data collection and METOC product distribution are closely examined for achieving the following goals:

(a) To evaluate new software from FNMOC as a transfer method for METOC information to and from a surface combatant.

(b) To determine if changes to current METOC data acquisition, distribution and reporting policies are merited.

(c) To evaluate the Moriah sensor suite concept for areas of improvement prior to its introduction to the fleet.

(d) To determine the role of the regional METOC center with respect to surface combatants in distribution of METOC data and products to the warfighter.

(e) To develop a comprehensive model of METOC information flow between surface combatants, battlespace managers, and METOC centers, as well as within the lifelines of the ship.

The thesis begins with an overview of METOC data collection techniques currently used by ships and those for automated systems planned for fleet introduction in the next three to five years. Chapter III discusses METOC products and their exchange, while Chapter IV describes new communication paths and their impact on METOC data and product distribution. This is followed by a description of the equipment, procedures, and results from an at-sea demonstration of an integrated METOC sensor suite. Chapter VI examines the effect of Moriah and METCAST on Navy operations and the role of the Navy Integrated Tactical Environmental System (NITES). The thesis is then summarized and a number of recommendations for various programs are offered, as well as ideas for follow-on work.

II. SHIPBOARD METOC DATA COLLECTION

A. LIMITATIONS OF CURRENT SHIPBOARD OBSERVATIONS

Continuous and accurate METOC data collection and reporting are necessities for naval operations. A primary deficiency of present observations seems to be that they are inaccurate, instantaneous measurements recorded at hourly intervals. In addition, only the synoptic observation (every six hours) is reported to shore sites for data assimilation. It is apparent that an improvement in the quality and granularity of METOC observations, without increasing the workload of watchstanders, is in order.

Observations of environmental data aboard surface ships are time consuming and often inaccurate. Personnel taking the measurements aboard surface combatants are also responsible for maintaining the official ship's deck log and various other duties throughout their watches that, unfortunately, do not always allow adequate time for accurate observations. The instantaneous measurement taken is not necessarily representative of actual conditions and the instruments used may not be properly calibrated or maintained for required performance levels. Figure 1 shows a comparison of barometric pressures observed by watchstanders and those recorded by the prototype Moriah system aboard USS Juneau. The disparity in pressure results from improper reading of the barometer, since trends of constant pressure can be attributed to specific watchstanders.

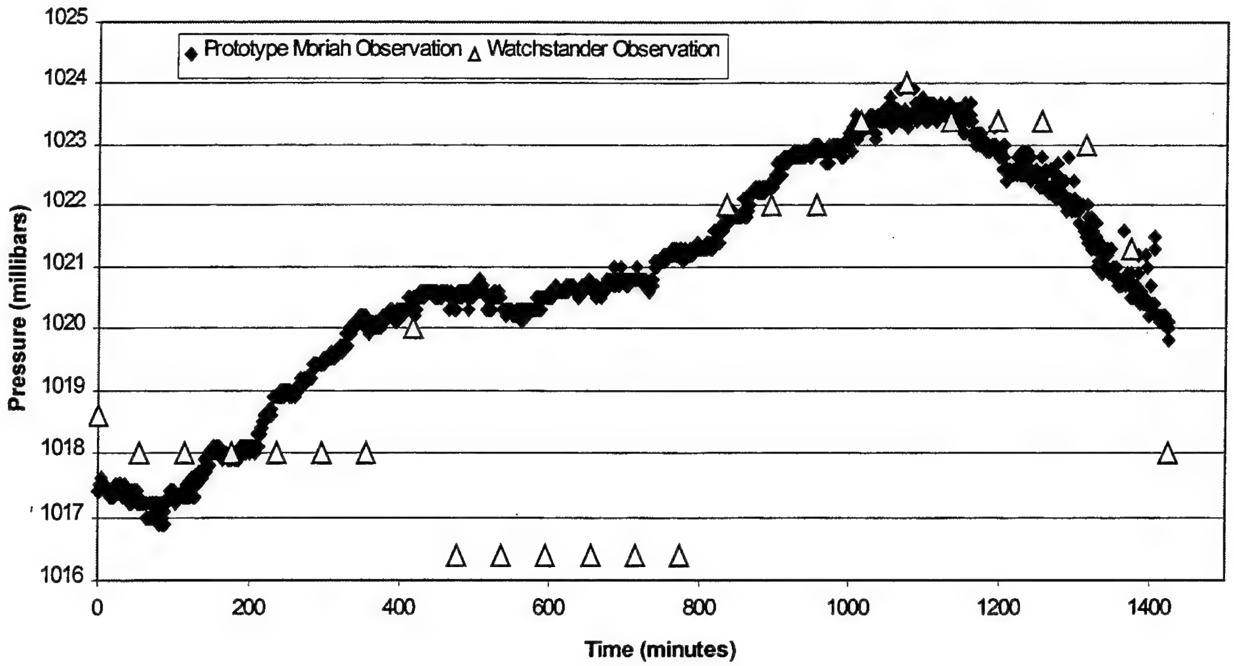

Figure 1: Comparison of Prototype Moriah and Shipboard Watchstander Observations of Barometric Pressure on 13 April 1999 aboard USS Juneau.

Figure 2 shows similarly inaccurate observations of relative humidity by watchstanders when compared to the Surface Combatant In Situ METOC Sensor (SCIMS) Suite aboard USS Hewitt (DD-966) during SHAREM 120B. The reason for the differences in this case was attributed to a malfunctioning hygrometer aboard the ship. Synoptic reports submitted from these two instances undoubtedly contained gross errors detrimental to numerical weather prediction and the calculation of atmospheric properties such as evaporation duct height and air-sea fluxes.

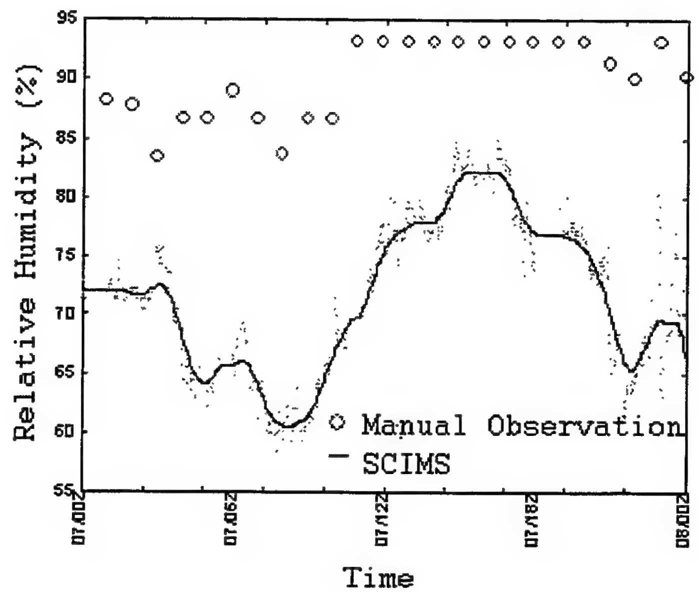

Figure 2: Comparison of SCIMS and Shipboard Watchstander Observations of Relative Humidity onboard USS Hewitt during SHAREM 120B.

The frequency of ship observations is based on antiquated data assimilation methods, which could only use synoptic scale information. The synoptic observations are generally transmitted every six hours and are frequently deemed inaccurate by quality control methods due to improper format, delay in receipt, or reports of conditions inconsistent with the current synoptic pattern. (Gustafsson, 1981) The Ship's Weather Observation Log, CNMOC Form 3141/3, provides a record of hourly conditions, however; this information only leaves the ship when mailed for archival and inclusion in climatological databases. This is unfortunate, since over-water observations are very important for forecast models as operations move into littoral regions.

Spatially, a higher density of observations is needed to improve resolution of environmental fields. Temporally, more frequent observations are needed to resolve events of a scale less than synoptic. However, to simply increase the reporting frequency would prove nearly impossible under today's labor-intensive methods. Hourly transmission of environmental conditions via naval message would require too much effort on the part of watchstanders and would undoubtedly result in even poorer quality observations.

The inaccuracies of shipboard observations are well known (Taylor, et al., 1993; Smith, et al., 1998), and have been addressed by the U. S. Navy in the form of the Moriah sensor suite, which is planned for installation aboard nearly all naval vessels. Moriah provides the continuous monitoring of environmental conditions required by today's combat system and relieves shipboard personnel from the burden of manual observations.

B. MORIAH OVERVIEW

The Moriah system is currently under development in a combined Oceanographer of the Navy (OP-096) and Naval Air Systems Command effort to improve both wind information measurements aboard aviation capable ships and the performance of weapons systems. SPAWAR PMW-185 and NAVAIR 251 are sharing responsibility for development and acquisition of Moriah components. NAVAIR 251 is providing wind measuring and processing equipment, while SPAWAR PMW-185 is providing sensors and processing for all other METOC parameters, including temperature, humidity, and pressure. Moriah consists of Commercial-off-the-shelf (COTS) environmental sensors, a

customized data acquisition and processing system, and various displays and interfaces. The class of ship will determine the exact complement of sensors installed, with aviation-capable, Aegis, and force-level ships receiving the most sophisticated equipment. Stringent requirements on performance were incorporated into the selection of sensors for Moriah to ensure high quality, reliable measurements. Collaboration between various research agencies, such as Johns Hopkins University Applied Physics Laboratory, Naval Research Laboratory Marine Meteorology Division, and the Naval Postgraduate School, and operational requirements developed by the Oceanographer of the Navy, Naval Air Warfare Center, Surface Warfare Development Group, Aegis Program Office, and the Naval Meteorology and Oceanography Command led to the development of the Surface Combatant In-Situ METOC Sensor (SCIMS) system as a test platform for various sensors. Numerous exercises and experiments resulted in the selection of sensors that will meet or exceed identified requirements. A SCIMS system is used as a prototype Moriah system for this demonstration since a Moriah system is not yet available for testing.

The following sensors and interfaces will be the minimum installed aboard a ship with Moriah:

- Anemometer
- Relative Humidity and Air Temperature Sensor
- Barometric Pressure Sensor
- Water temperature Sensor
- Insolation sensor
- Radiosonde receiver interface

The following systems may be installed as part of Moriah depending on ship type and/or mission:

- Ceilometer
- Visibility Sensor
- Rocketsonde System
- Environmental Assessment System (unique to Aegis ships)

Moriah sensors will provide continuous monitoring of the ship's operational environment, a vast improvement over instantaneous hourly measurements. Small changes in atmospheric conditions normally missed by watchstander observations will be measured and made available to ship systems and operators.

Moriah is designed to display METOC information in various locations throughout the ship and provide a direct feed of METOC data to designated systems. A primary workstation will provide an interface to environmental data, as well as system administration functions and the Quartermaster's Environmental Log (QMEL) program. QMEL is currently designed to assist in the completion of, but not replace, CNMOC Form 3141/3, the Ship's Weather Observation Log. Automation of this process will virtually eliminate typographical errors resulting from manual creation of a weather observation message.

Moriah also makes provisions for transmission of the standard synoptic observation via the Defense Message System. No other data is, in current plans, to be transmitted off the ship. Certain ships will have a local database whose information will be available to off-ship users via a data "pull" transaction. However, the majority will simply have Moriah systems that provide METOC information solely for ownship use.

Regrettably, a wealth of environmental information not previously available is currently planned to remain within the lifelines of the ship. However, by using electronic data transfer methods, Moriah can become a primary source of environmental information for a multitude of users, such as mesoscale models, METOC shore stations, and warfare commanders.

Figure 3 compares the path of an observation taken under current methods with that taken by a Moriah system configured to submit observations via automatic electronic transfer into the METCAST architecture. The observation methods in place today require a shipboard watchstander to manually operate a sling or electric psychrometer; record/convert readings from a barometer, thermometer, and anemometer; visually determine cloud type and coverage, wave height and direction, and current weather; and contact engineering personnel for seawater intake temperature. Of note, the current synoptic observations are limited to recipients of the message and subscribers to the Automated Weather Network (AWN) and fleet broadcasts. Every Moriah observation, however, is available to each end user within minutes via a METCAST subscription. FNMOC serves as the single collection and dissemination agency for all Moriah observations and is responsible for providing these observations to applicable end users via METCAST or other means. This provides a single point of contact for Moriah systems to transmit observations, eliminating unnecessary system configuration changes by shipboard personnel. This method also relieves undue burden on the ship's limited bandwidth by allowing interested units to retrieve the observation from FNMOC vice accessing the ship's local database.

C. ELECTRONIC TRANSFER OF SHIP OBSERVATIONS

Under current plans, ship observations taken by Moriah will be sent every six hours via standard naval message traffic. Hourly observations will be recorded, both electronically and manually, with a local archive retained within Moriah. The standard CNMOC form 3141/3 will continue to be completed, by hand, and mailed for archival each month. Off-ship submission of observations by naval message will require interaction with shipboard personnel and increase the transmission time. Automatic electronic transfer of the observation as a Multi-purpose Internet Mail Extension (MIME) compliant e-mail message is the most efficient method to transmit observations from a surface combatant.

E-mail offers a number of advantages over other transport methods and is especially attractive for Moriah systems located aboard surface combatants with the limited bandwidth and stability of ADNS. Benefits of include:

1. E-mail is compatible with IP networks.
2. Numerous tools and security mechanisms already exist for customizing and protecting e-mail contents.
3. E-mail is a well-known transport method and will be recognized by fleet operators.
4. The emphasis on electronic commerce for the Internet will continue to improve e-mail functionality and security.

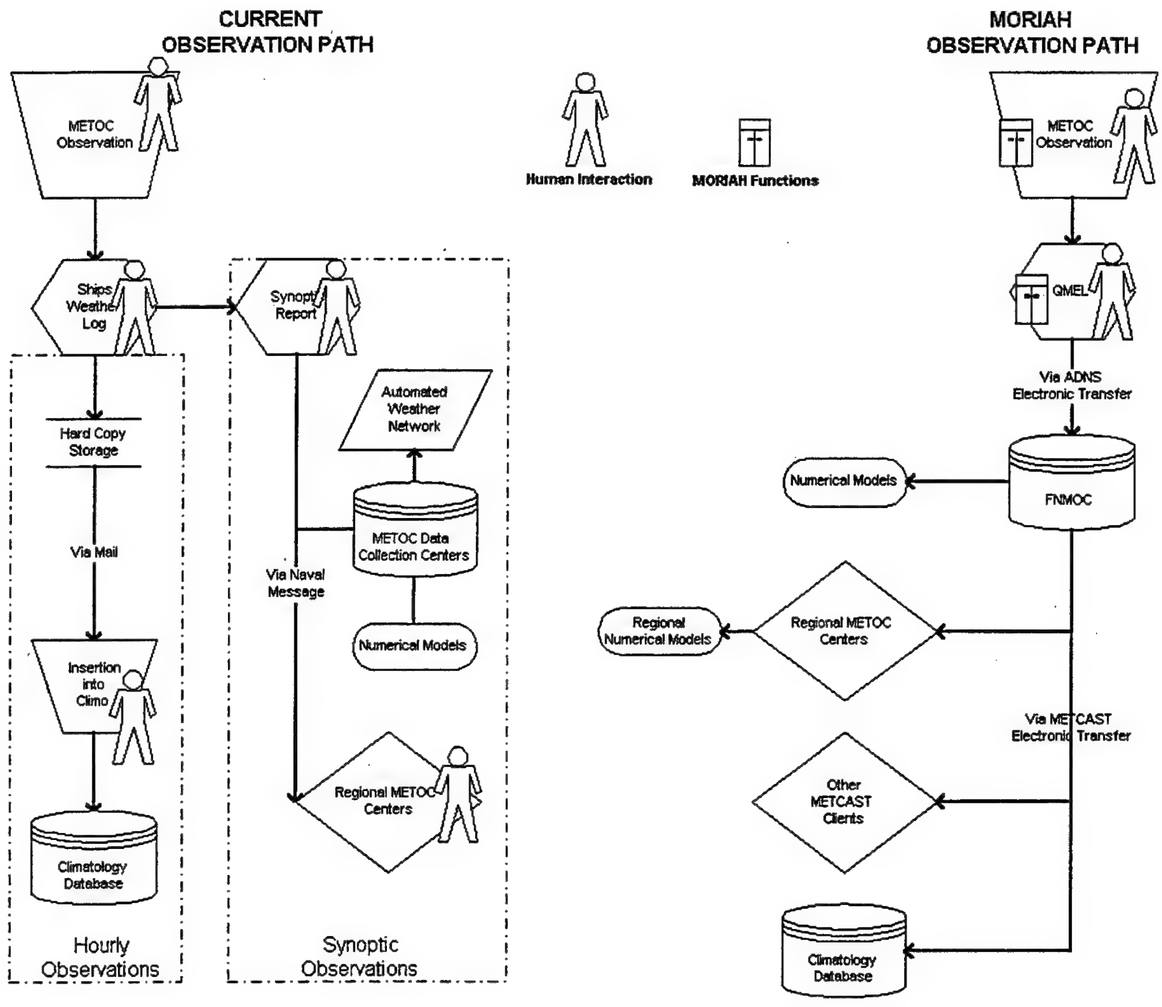

Figure 3: Comparison of Current Manual Observation Path to Proposed Man-machine Observation Path with Moriah System

D. IMPACT OF AUTOMATED SURFACE WEATHER OBSERVATIONS

Automated systems such as Moriah will improve the performance of numerical prediction models by providing highly accurate and more frequent observations of the environment. In turn, these models will provide improved support to the fleet in the form of better forecasts and enhanced tactical decision aid (TDA) performance. Mesoscale models, such as the Coupled Ocean/Atmosphere Mesoscale Prediction System

(COAMPS), data assimilation schemes, battlespace visualization, and nowcasting all require higher frequency environmental observations from in-situ platforms. By optimizing both the observation and the submittal process through automation and streamlined data flow, the accuracy, frequency, and timeliness of ship observations will help satisfy the fleet requirement (Chief of Naval Operations N091, 1998) to:

> "Develop technologies to provide the capability to perform the following real-time in situ environmental monitoring and analysis of the natural forces that act upon platforms/weapons while they are deployed:
>
> 1. Monitor and measure relevant in-situ geophysical, marine biological, magnetic, optical, oceanographic, hydrographic, and meteorological parameters.
>
> 2. Link these data in real time with historical databases of related data to provide real-time display.
>
> 3. Provide instantaneous analysis in an understandable format to the task force commander and other local or remote users."

As shown in Figure 4, the need for direct observations becomes increasingly more important as an operation transpires. Initial, long-range planning can use climatology, but high frequency, in-situ measurements by ships, aircraft, ground forces, etc. are critical for the Rapid Environmental Assessment (REA) that must occur in the period just before, and during, the start of the mission (Whitman, 1997).

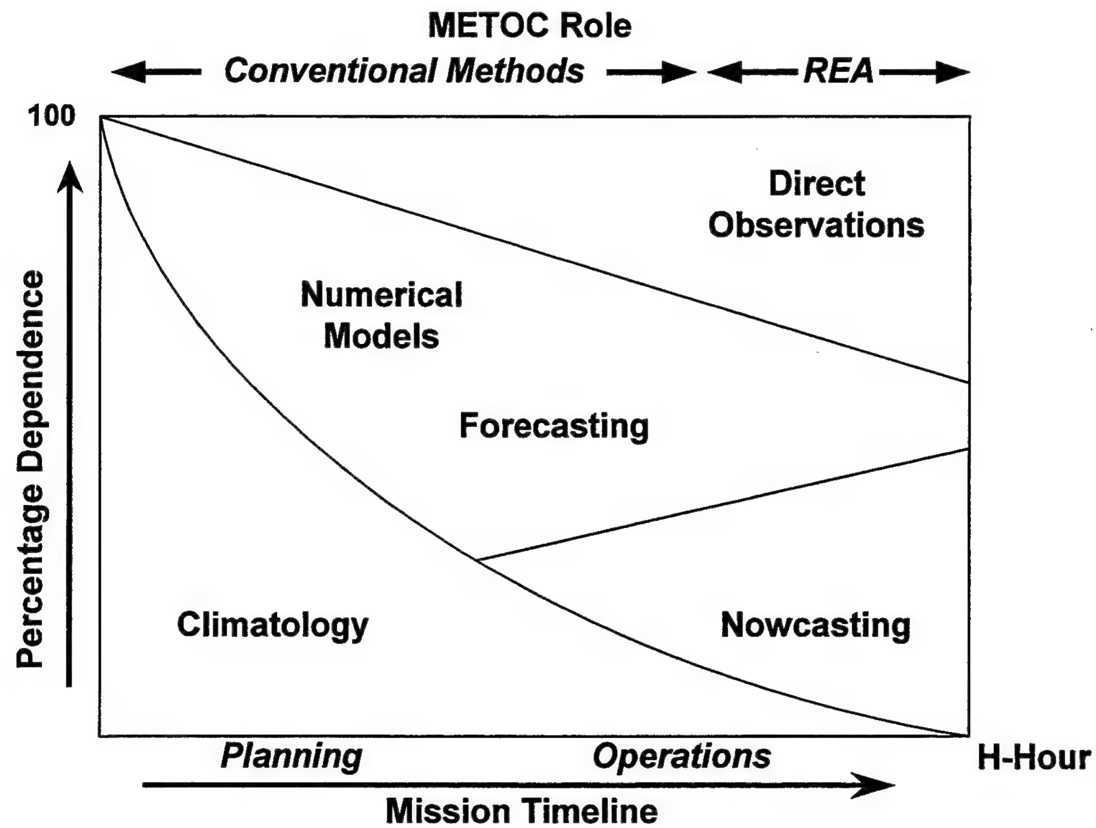

Figure 4: Role of METOC Elements in Mission Planning and Operations in Rapid Environmental Assessment (REA) (after Whitman, 1997).

Since the performance of the numerical models and the skill of forecasting/nowcasting are also highly dependent on accurate, local measurements, their importance cannot be over-emphasized.

E. SHIPBOARD DATA ARCHIVAL PROCESSES

Moriah will be configured to record automated measurements and prompt the watchstander for observations that cannot be automated, such as wave direction and height, cloud type and coverage, visibility, weather and obstructions to vision, and

significant weather phenomena such as funnel clouds, squalls, and precipitation. Once these manual observations are entered, the watchstander duties should be complete. The QMEL segment of Moriah should archive and periodically transmit the locally archived digital ship's weather log to a designated repository. Electronic Records Management (ERM) techniques should be employed to archive Moriah information in an effort to eliminate the requirement for manual completion and submission of the Ship's Weather Log for archival. ERM, if implemented properly, allows information to be digitally stored in a standardized format that could satisfy the archival and record-keeping requirements of NAVMETOCCENINST 3144.1D. ERM also provides improved access to archived records through index searches and queries that can automatically sort information based on user-defined parameters. (Long, 1998)

The type of media used to archive Moriah information needs to be addressed to ensure shipboard survivability and compatibility with other archival systems located ashore. Optical storage, i.e. CD-ROM, is a possible candidate that can provide high capacity storage and ease of use for shipboard personnel. CD-ROMs are less susceptible to the dangers of shipboard electromagnetic emissions than other storage devices and are easily transported. Another option for storage would be to simply transfer the archived data files electronically off the ship to a shore collection site. Archiving, by any method, must also include an identification method that verifies authenticity of the information. This can be accomplished under the DOD Public Key Infrastructure (PKI), a system designed to provide a variety of services (i.e. data integrity, user identification and authentication, user non-repudiation, data confidentiality, encryption and digital

signature) for programs and applications that use the DOD networks. (Defense Information Systems Agency, 1999) A digital signature should be applied by Moriah to each observation and to the final archive, that departs the ship. This prevents altering of observation elements and maintains a mechanism for tracking accountability.

To summarize, ERM of Moriah information is an efficient, sensible process that will eliminate manual intervention, provide higher levels of security, improve access to historical data, and satisfy federally mandated record keeping directives.

III. METOC PRODUCTS FOR THE SURFACE COMBATANT

A. TRADITIONAL METHODS OF METOC DATA DISTRIBUTIONS

Conventional METOC support to surface combatants has consisted of text message traffic, High Frequency radio facsimiles, Joint Maritime Command Information System (JMCIS) overlays and the occasional deployment of a Mobile Environmental Team (MET). While these services are valuable, today's surface ships require more advanced environmental information to effectively use weapons systems and ensure safety of navigation. Simple overlays and text representation of environmental products such as high winds and seas warnings, refractivity conditions, and the location of ocean fronts and eddies, are not flexible nor robust enough to convey appropriate tactical information. The addition of METOC personnel, such as a MET, to ship's company is an important service. However, with the exception of some additional products sent via naval message traffic, climatological decision aids and possibly an upper air sounding, the Aerographer's Mate (AG) brings no new data to the ship, only invaluable METOC knowledge and experience. In addition, the reliability of existing support is highly variable; HF radio reception can be an exercise in futility and message traffic can be significantly time late.

For ships equipped with high bandwidth SIPRNET or NIPRNET connections, such as aircraft carriers, there is essentially no limit to the amount and content of METOC products available. High-resolution satellite imagery, gridded model field information, tailored forecasts, and Internet chat sessions are available from numerous sources to

support the embarked OA (METOC support) Division. For surface combatants, who generally have no embarked METOC personnel, METOC information through SIPRNET or NIPRNET has not been an option. This poses a challenge to METOC commands that must provide support to these ships in a compact, efficient, and easily understood format through very limited communication paths.

An example of fleet support functions that require improved METOC products is that of ship weather avoidance or Optimum Track Ship Routing (OTSR). OTSR is a primary function of regional METOC centers and is highly regarded by the surface ship community. Aircraft carrier OA divisions can provide on-scene updates of the situation based on a variety of METOC data sources. This is not the case for surface combatants, as shore-based METOC forecasters often spend a significant amount of time conversing by satellite telephone with the affected ship. Satellite images and up-to-the-minute guidance cannot be sent in near real time, so voice contact is often used to provide the ship's Commanding Officer with all pertinent information to ensure the safety of his ship and crew will not be compromised. The metrics of the Commanding Officer's comfort level cannot be quantified, but current METOC support to ships with limited communication suites lacks the required robustness to ensure this decision can be reached without human interaction.

These traditional methods of support fall short in providing appropriate METOC guidance to surface combatants. However, without improved communication systems, METOC support for surface combatants will continue to provide "bare minimum" information to the warfighter.

B. METCAST OVERVIEW

METCAST is a request-reply and subscription distribution system for METOC information (Kiselyov, 1999). METCAST is still under development, but will provide significant improvements to the transfer of METOC products and data. In the simplest terms, METCAST is comprised of the following:

(a) A client, or retriever, resident on the user's workstation, which is used to generate requests for METOC information.

(b) A METCAST server that responds to user requests for METOC information and returns appropriate products to the user.

(c) A METOC database of products called the Tactical Environmental Data Server (TEDS).

The METCAST client interface allows a user to define a geographic area anywhere in the world, select desired METOC products, and establish a schedule for the request of those products. Based on this schedule, the retriever will automatically poll the METCAST server, which will determine if updated products are available. The client then executes a "pull" transaction to download these updates where a viewer application (generally the Joint METOC Viewer) is launched to display the area with the downloaded information. If the viewer is already running, its display will automatically refresh. This allows the user to have the most up-to-date information available without having to manually retrieve the products. Available METOC products, such as observations, gridded fields, and satellite images can be selected from a dynamic product list that is also periodically updated to show only those products currently available for the selected area.

Currently, a variety of methods is used to retrieve METOC products and data. The primary tool is via the Joint METOC Viewer, a follow-on to the Navy Oceanographic Data Distribution System (NODDS), that allows a user to choose desired METOC data for a defined area. However, JMV requires a manual download of data fields and does not have a capability for automated product publication and retrieval. Products created at METOC centers and facilities are only accessible from SIPRNET/NIPRNET homepages, HF Facsimile broadcasts, or JMCIS overlays. METCAST serves to provide "one-stop shopping" for METOC information.

METCAST uses standard MIME messages for data distribution via Hypertext Transfer Protocol (HTTP). HTTP also allows METCAST to use standard World Wide Web (WWW) configurations such as proxies, gateways, authentication, etc. to securely and efficiently transfer METOC information. HTTP is more efficient than File Transfer Protocol (FTP), as it requires only a single connection between client and server versus two connections required for FTP.

An additional feature of METCAST is a "channels" capability (Kiselyov, 1999). Channels can contain pieces of information of any origin and format; i.e. software updates, presentations, METOC products, documents, etc. The user subscribes to desired channels, which are then downloaded in the manner described above. With proper permissions, users can also publish information to channels for dissemination to other METCAST clients. This publishing feature provides a unique conduit for the transfer of tailored information from Regional METOC Centers to afloat forces.

C. METOC PRODUCTS AND THE REGIONAL METOC CENTER

The dissemination of METOC products to surface combatants is revolutionized by METCAST and ADNS and will require an expanded role for the Regional METOC Center. Network connectivity to ships will drive a dramatic change in METOC product content and format. As depicted in Figure 7, text messages, facsimile products, and geometric JMCIS overlays will give way to advanced, high resolution, digital products capable of conveying significantly more information. Current legacy and stovepipe communication paths maintained by METOC centers will migrate to a single network connection. The ship will have access to digital METOC information from LAN workstations versus hard copy messages.

To accomplish this, however, the center must be actively involved with ships in their region. An aggressive Fleet Support program will be required to:

(a) Assist in the installation and operation of METCAST clients.

(b) Train shipboard personnel on the use and interpretation of next generation METOC products.

(c) Manage the distribution of METOC information within their region to prevent saturation of ADNS links.

(d) Ensure ships without embarked METOC personnel are not receiving information requiring further interpretation, i.e. gridded model fields.

(e) Create enhanced METOC products that satisfy shipboard requirements and exploit the full network capabilities.

Once the benefits of METCAST are demonstrated to the fleet, it is inevitable that the demand for additional tailored METOC products will increase. METOC centers will need to exercise caution to avoid overloading their own personnel and should explore

information distribution methods, such as multicasting and shipboard caching, to provide common products to all ships when possible.

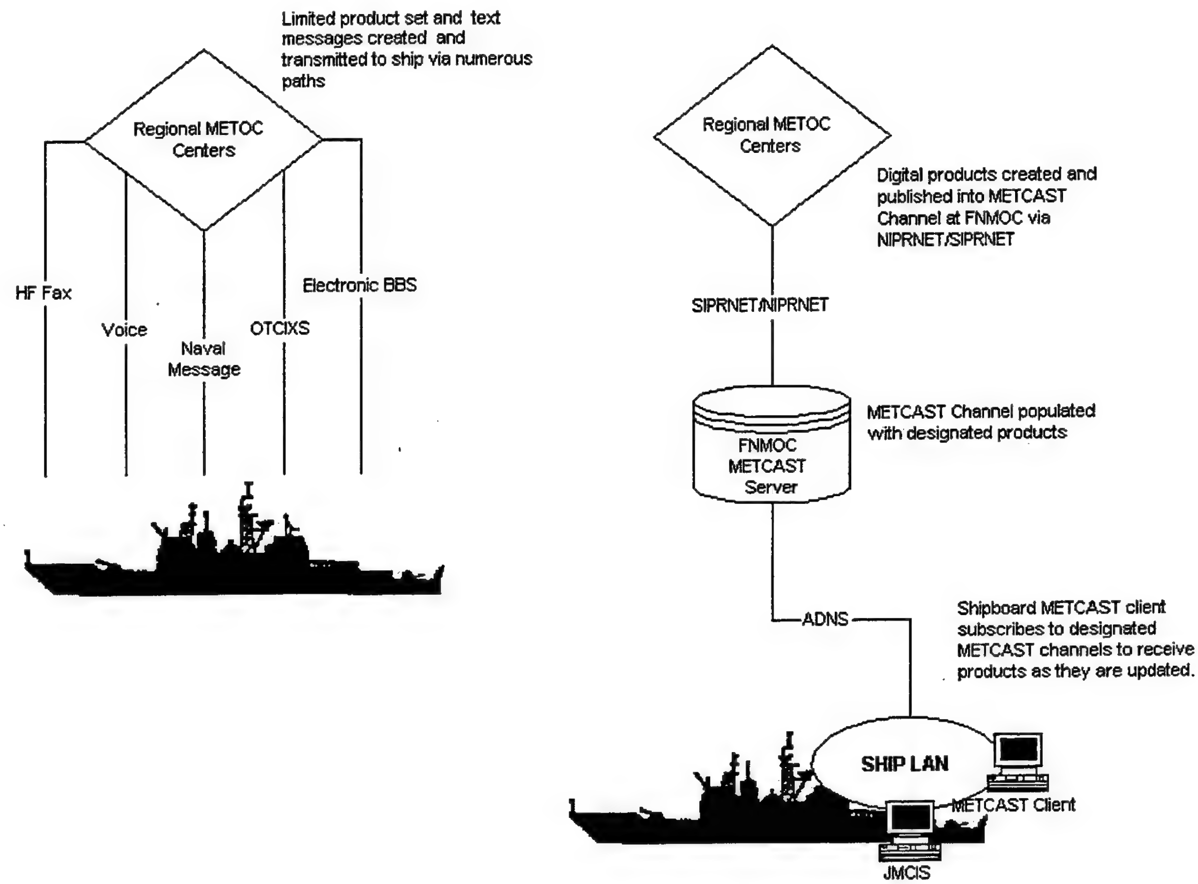

Figure 5: Conventional METOC Product Transmission Methods Versus METCAST Distribution.

IV. COMMUNICATIONS

A. METOC POLICY FOR COMMUNICATIONS

The Oceanographer of the Navy (1996) established a METOC Communications Policy, which outlines the direction the METOC community will take with respect to METOC information flow. The primary goal for METOC communications is to become an integrated segment of the National Information Infrastructure (NII)/Defense Information Infrastructure (DII). Of note, the decision to abandon stovepipe METOC communication methods has cleared the way for closer integration of METOC assets with fleet units and provided a common standard to which new acquisition and distribution systems, such as Moriah and METCAST, could be developed. This policy encourages exploitation of all available communication paths and the use of Commercial-off-the-shelf (COTS) and Government-off-the-shelf (GOTS) software to ensure success of the Battle Space METOC Data Acquisition, Assimilation, and Application (BMDA3) vision.

B. ADNS OVERVIEW

ADNS is a radio Wide Area Network (WAN) that transparently and seamlessly extends military network connectivity to ships at sea. Data transfer via ADNS is the same as that occurring within shore networks; i.e. standard IP practices are in effect.

As part of the Joint Maritime Communications System (JMCOMS), ADNS is designed to provide reliable, timely, and adaptable network communications to afloat units anywhere in the world. ADNS will automate numerous existing communications

systems by encapsulating proprietary, stovepipe networks into packets or "IP datagrams." These datagrams are then aggregated and transmitted through a single interface, in the form of a common IP router, to other networks.

ADNS is composed of three functional elements (Joint Maritime Communications System, 1998):

(a) Integrated Network Management (INM)-a three level system capable of local and remote performance monitoring and system asset control through use of commercially available, standards based management protocols such as Simple Network Management Protocols (SNMP).

(b) Routing and Switching (R&S)-a combination of IP addressing, routing functions, and switching equipment to direct network data via JMCOMS. Dynamic routing using the Open Shortest Path First (OSPF) protocol enhances efficiency.

(c) Channel Access Protocol (CAP)-the primary management tool for the JMCOMS network. CAPs are created for each specific communication system (i.e. UHF DAMA, EHF, etc.) to allow integration into ADNS. CAPs monitor network quality of service, generate loading and error reports, and provide statistics necessary for calculation of dynamic routing functions.

Figure 6 portrays a simplistic ADNS architecture and its relation to military networks and METOC centers. The Network Operating Center (NOC) is the link between ADNS and other DII networks, such as SIPRNET and NIPRNET. The NOC monitors communications circuits and provides a myriad of web services such as email store and forward services, proxy servers, firewall protection, and gateways to NIPRNET and SIPRNET.

Onboard ships, network configuration is standardized and may include LANs of differing classification. Figure 7 portrays a simplified typical shipboard ADNS topology

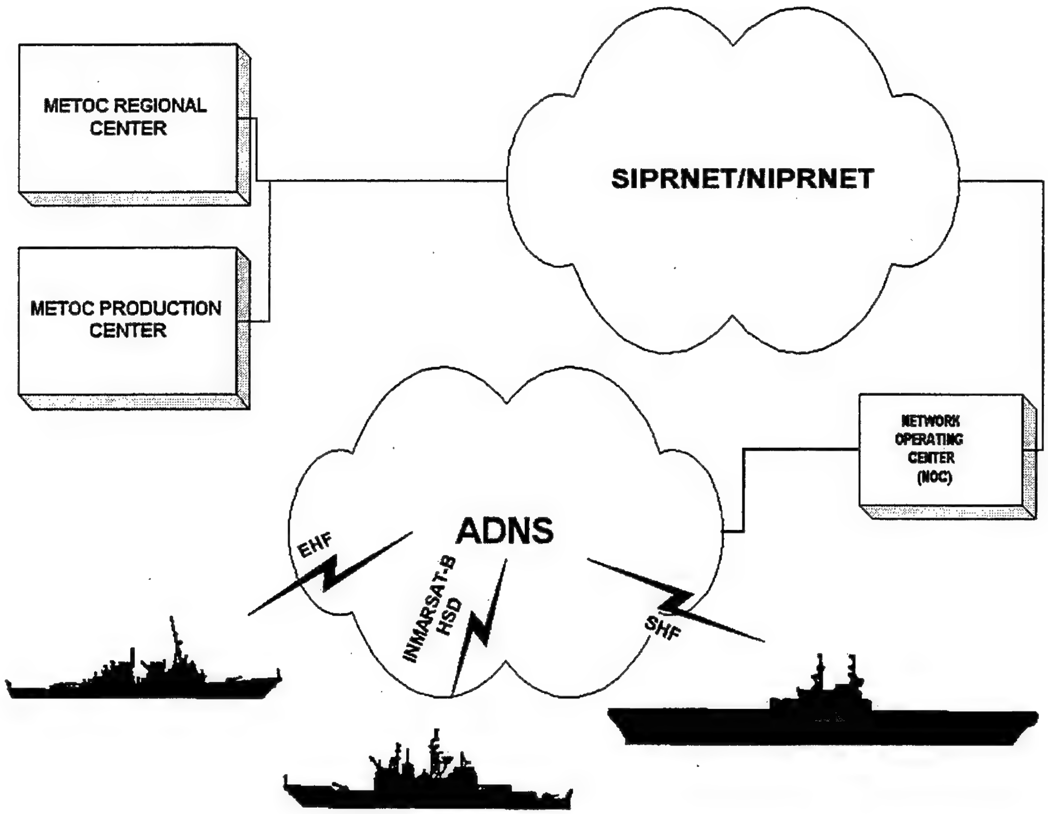

Figure 6: Simplistic Network Architecture for Connectivity between METOC Shore Components and Ships.

consisting of INMARSAT-B High-Speed Data (HSD), the Digital Wideband Transmission System (DWTS), (a line-of-sight wide area network (WAN) unique to amphibious ships), and pier-side connections. Depending on the specific communications capabilities and requirements of each ship, ADNS can also include SHF, EHF, UHF DAMA, and HF circuits. Future communications circuits can easily be included in the ADNS architecture by simply creating an appropriate CAP. Surface combatants are not typically outfitted with SHF SATCOM and current throughput for EHF and UHF circuits is limited.

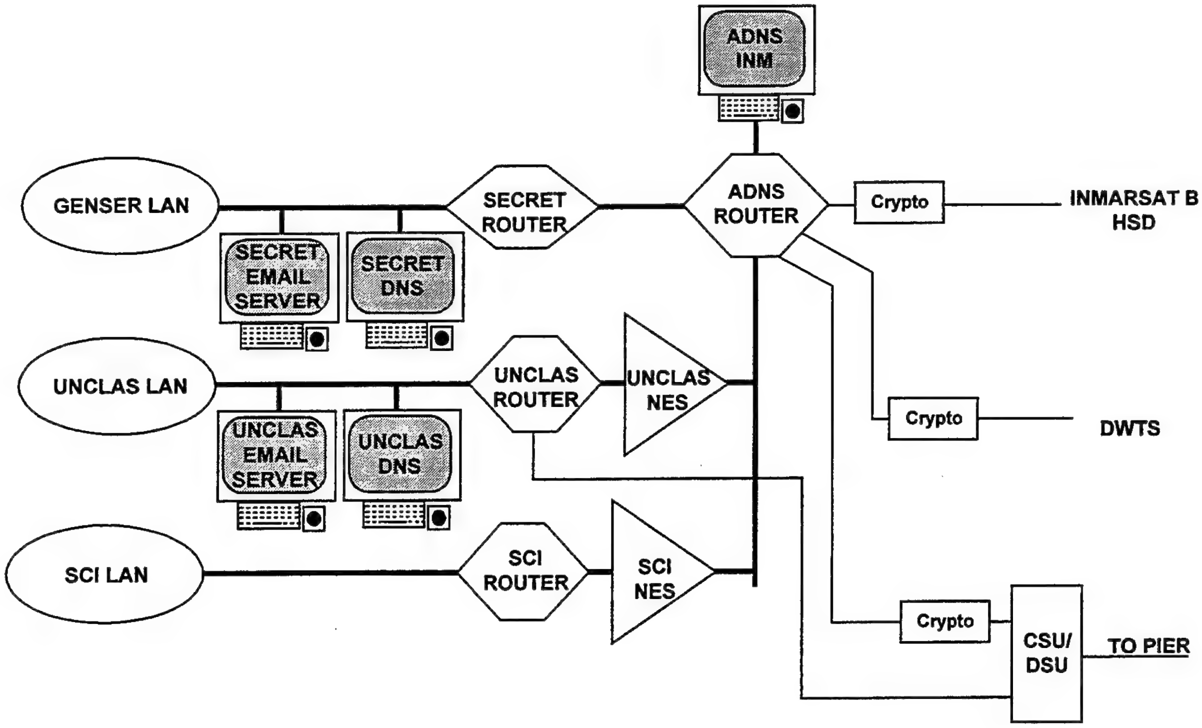

Figure 7: Typical Shipboard Network Topology (after SPAWAR Systems Center San Diego)

As depicted in Figure 7, Unclassified, GENSER Secret, and Specially Compartmented Information (SCI) LANs each have a dedicated router which determines how IP datagrams will leave the ship. The use of Network Encryption Systems (NES), an early version of Virtual Private Networks (VPN), allows information of various classifications to be transmitted off the ship via a single network connection. After passing through the NES, the now encrypted information is relayed to appropriate shore NES by the ship's ADNS router.

USS Juneau is equipped with INMARSAT-B HSD terminals as the primary ADNS component. This thesis will focus on USS Juneau's INMARSAT-B HSD system,

but the dynamic routing feature of ADNS will determine the best route to deliver IP datagrams.

INMARSAT-B HSD systems provide dedicated, full-time connectivity with variable voice/data rates up to 64 KBPS aggregate, including voice and a data link for NIPRNET/SIPRNET at a nominal data rate of 32 KBPS (Joint Maritime Communications System, 1997). INMARSAT-B HSD is currently being installed on a number of ships as they begin deployment workups and access will be provided for each ship for the duration of the deployment. ADNS access may be available through other communications paths, such as UHF and EHF SATCOM, but these systems will provide much slower data rates, on the order of 1200 to 2400 BPS. Email exchange and limited WWW service would remain available.

C. GLOBAL BROADCAST SERVICE

The Global Broadcast Service (GBS) is a one-way, shore to ship continuous broadcast of information designed to provide significantly higher bandwidth (on the order of 20 Mb/s) than is currently achievable. The high volume data transfer capacity of this system is especially attractive for large files, such as satellite imagery, streaming video, and 3-D METOC products. This system, however, presents unique networking challenges in that shipboard replies to shore data transfers cannot return via the same path, a reachback channel on another circuit or network must be used. For example, upon receipt of a file over GBS, the ship could return appropriate acknowledgement messages via ADNS. The routing and switching configurations must be able to identify GBS

packets and reply via ADNS to maintain integrity of the data transfer. Although still under development, GBS appears to offer a solution to the limited network communications of surface combatants. GBS is planned as a component of ADNS (Joint Maritime Communications Systems, 1999), so no significant changes to METCAST distribution will be required. However, should GBS remains isolated from ADNS, it is important that METCAST be adapted to operate over this unique network.

V. PROCEDURES AND RESULTS

A. OVERVIEW

Completion of thesis goals required both a systematic verification and an operational evaluation of a combined METCAST/Moriah system. System verification was required to initially prove METOC data transfer could be automated and was accomplished ashore through landline network connections. An at-sea demonstration of the concept was then required to determine the value and feasibility of this concept under operational conditions.

B. HARDWARE COMPONENTS

A prototype Moriah system, a variant of the SCIMS system, was assembled to provide a continuous source of METOC data for the demonstration. The components of the system were selected to demonstrate the value of continuous transmission of METOC data via ADNS and METCAST.

This system contained the following sensor and controller components:

- GPS Receiver
- Anemometer
- Air Temperature/Relative Humidity Sensor
- Infrared Sea Surface Temperature Sensor
- Barometer
- Magnetic Compass
- Datalogger

All instruments were mounted on an aluminum "METOC tower" of approximately 10-feet in height. Specific sensor information is located in Appendix A.

C. METOC COMPUTER HARDWARE/SOFTWARE

The tower datalogger was connected to the serial port of a notebook computer, which, with associated software, was the critical element in this demonstration. This METOC computer was interfaced with a LAN and used COTS software to interface with the datalogger for programming and data retrieval, and to conduct simple averaging of acquired data. Locally developed software was used to format the data into a recognizable format and to transfer the observation file off the ship. Figure 8 shows a modular data flow of this specific system. It is important to note that the transfer of the observation file off the ship can be accomplished by any number of processes, such as e-mail, FTP, or HTTP transactions. This allows the type of electronic transfer to be easily adapted based on the type and capacity of available communications.

Data retrieval and processing was accomplished by Campbell Scientific® PC208W Datalogger Support Software. This software package provided the interface to the METOC tower's CR10X datalogger and was used to perform data averaging functions. To format the data into acceptable World Meteorological Organization (WMO) synoptic code, Microsoft® Visual Basic was used to develop a formatting program with assistance from Naval Research Laboratory Marine Meteorology Division, Monterey, CA. This software ingested the averaged METOC tower data and provide a standard ship synoptic observation as required by Commander, Naval Meteorology and Oceanography Command (1996), with the exception of cloud, visibility, precipitation, and wave information. Automated shipboard measurements of these phenomena have yet to be perfected. This deficiency in the demonstration was not important for the purposes

of this study. A description of the synoptic code and sample observations can be found in Appendix B.

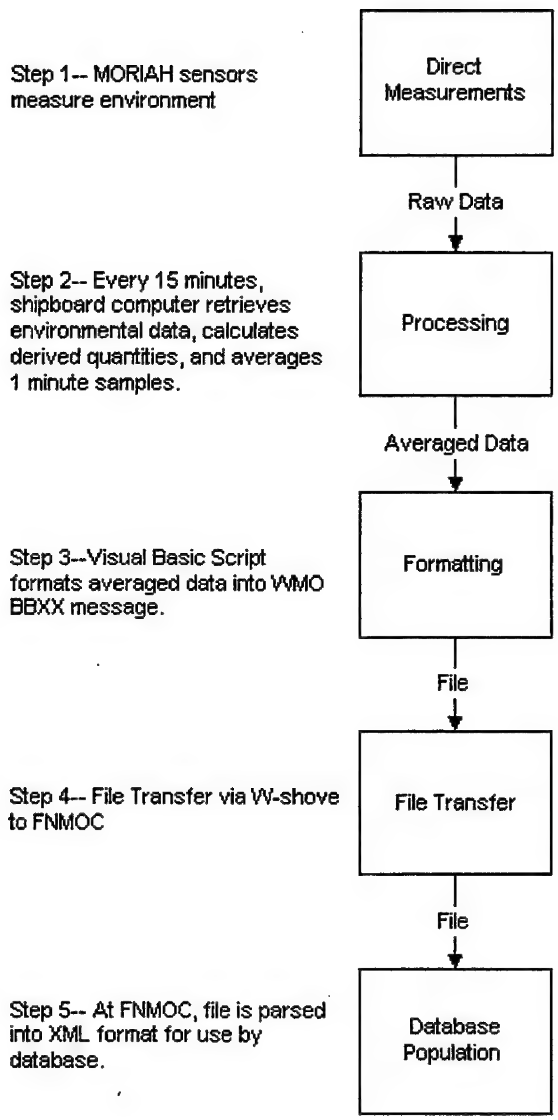

Figure 8: Prototype Moriah Observation Flow from Point of Measurement to FNMOC Database.

Once the report was formatted into a standard WMO message, software provided by FNMOC generated an HTTP Put transaction to place the observation into a METOC database. This software, "w-shove", is normally used by METCAST to distribute information (Kiselyov, 1999). In this case, it was used in reverse to automatically send METOC observation files from a source to the METCAST server and subsequently into a METOC database. In the future, this database function will be fulfilled by TEDS. This alternative use of w-shove is an important feature in this demonstration since a capability was being tested for the first time in an operational setting. Once w-shove placed the observation file in the database, it was parsed into extended markup language (XML) format and made available for retrieval via METCAST.

D. PHASE ONE – SYSTEM VERIFICATION

For development and test purposes, the METOC Tower was initially erected atop a three-story building (Bldg. 702) at FNMOC. The METOC computer was located in a computer system development space within the same building. The system transmitted a simulated ship observation every fifteen minutes to the FNMOC METCAST server via a terrestrial LAN. This observation was subsequently retrieved using the METCAST client installed on the METOC computer. The above process was completely automated; no human intervention was required.

This landline test verified that automated observations could indeed by efficiently transferred to and from a METOC database via HTTP processes, given stable network

connections. The next step, an operational evaluation, was to determine the feasibility of utilizing these same transport methods over a Radio WAN, i.e. ADNS, to ships at sea.

E. PHASE TWO – AT-SEA DEMONSTRATION

For the at-sea demonstration, USS Juneau (LPD-10) agreed to embark the METOC Tower and associated computer during Littoral Lightning, the second phase of Fleet Battle Experiment Echo, from 5-16 April 1999 in the SOCAL operating area.

NIPRNET was chosen as the communication path for the demonstration with access through ADNS provided by a 32 KBPS INMARSAT-B HSD connection that had recently been installed aboard USS Juneau. For demonstration purposes, the METOC computer was networked with the USS Juneau's unclassified LAN in the ship's METOC office. The METOC tower was erected on the starboard side SLQ-32 antenna platform. This location was not optimum for wind calculations due to superstructure influence. This was not considered a detriment to the demonstration, however, because the goal was to demonstrate automated transfer of an observation.

The METCAST client immediately proved to be a useful resource to the embarked MET by providing access to near real-time surface observations and terminal aerodrome forecasts (TAF) from various stations in SOCAL. Additionally, the ability to use the WWW to retrieve other unclassified products, such as forecast discussions, horizontal weather depictions, and regional satellite imagery, greatly enhanced the MET's ability to provide METOC support to the ship and embarked Explosive Ordnance Disposal personnel. Figure 9 is an example of high-resolution geostationary satellite

imagery provided, via e-mail and WWW, by Naval Pacific Meteorology and Oceanography Facility, San Diego (NPMOF-SD). Imagery of this quality and frequency has not been available to surface combatants, but can now be easily and automatically provided via METCAST and ADNS.

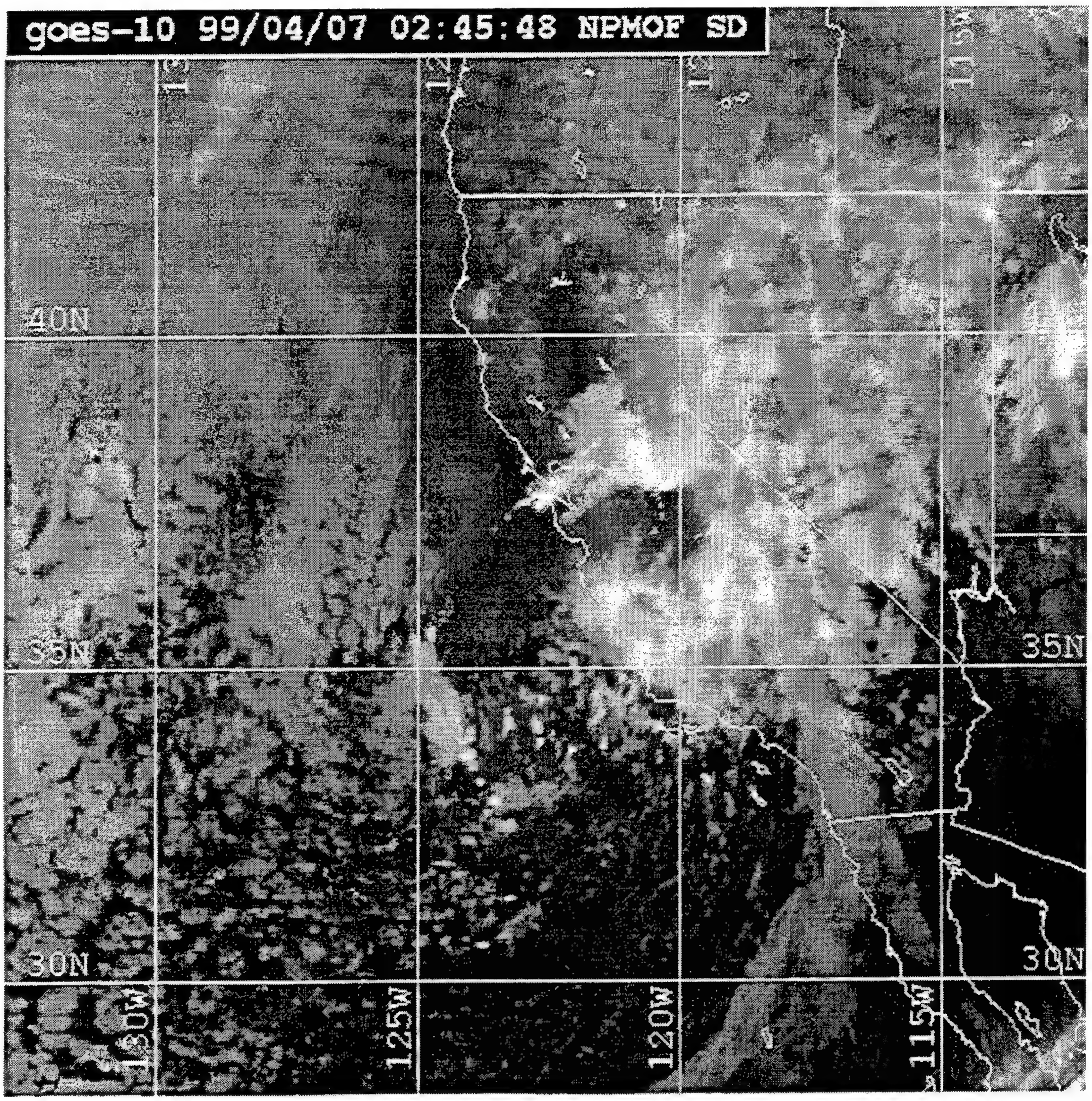

Figure 9: GOES-10 Infrared Satellite Image for California and Adjoining Waters for 07 Apr 99 0245Z.

The submission of observations from USS Juneau into the METOC database at FNMOC was not as successful as that experienced during system verification. Repeated attempts were made to transfer the observation from USS Juneau to FNMOC using w-shove. It was immediately recognized that the HTTP Put requests did not survive on the route into FNMOC. Troubleshooting of the problem while at sea revealed a problem in the firewall configuration at the Pacific Region Network Operating Center (PRNOC). The initial Put request was being received at FNMOC, but no other information was passed and the connection timed out after 5 minutes. Subsequent troubleshooting on the FNMOC/PRNOC link determined that the current version of the PRNOC firewall software was not completely HTTP 1.1 standard. Possible solutions for this are currently under discussion, but standardization of the PRNOC firewall in accordance with Department of the Navy (DON) Information Technology Standards Guidance (ITSG) (DON Chief Information Officer, 1999) should allow this method to succeed.

Due to the inability of the prototype Moriah system to have observations automatically sent via an HTTP process, an alternate scheme was devised to use an e-mail link as a transport method. In this scheme, observations were manually sent from a shipboard e-mail account to FNMOC with a designated subject line. Upon reaching FNMOC, the email was automatically registered as USS Juneau's observation and was placed in the METOC database. The observation was then retrieved via the shipboard METCAST client. Fifteen attempts of this manual transfer method were conducted and all were successful.

During this demonstration, USS Juneau's ADNS INMARSAT-B HSD link did experience a small number of outages that prevented network connectivity. It was beyond the scope of the demonstration to effectively monitor off-ship network performance, however, connectivity to NIPRNET was deemed reliable. The outages that did occur resulted from communication and cryptographic equipment malfunctions, signal masking by the ship's superstructure, or atmospheric conditions. Adding to these, ADNS is relatively unfamiliar to most shipboard operators who may lack appropriate documentation, training, and experience. These are common problems and must be considered when determining the transmission method of time-critical data over ADNS links. It is expected that system knowledge and performance of ADNS will improve over time as the program matures and will provide stable, efficient connectivity to ships at sea. METCAST is designed to handle network problems and performed as expected onboard USS Juneau. If a retrieval transaction failed after five attempts, the software would assume a network problem and wait for a designated amount of time before attempting the transaction again. METCAST has a monitor feature which logs all transactions and provides alerts should problems occur. This proved very useful in determining the status of USS Juneau's offship network connection.

VI. DISCUSSION

A. BENEFITS OF INTEGRATION

The addition of Moriah, METCAST, and ADNS to surface combatants offers an opportunity for the U. S. Navy to reach a higher level of METOC support and data collection. As Moriah and other in-situ and remote sensors record and submit accurate observations, METCAST can provide the ship with enhanced METOC products from a multitude of sites. This integration is defined as Battlespace METOC Data Acquisition, Assimilation, and Application (BMDA3) by the Oceanographer of the Navy (1996) as a common tactical picture in which environmental conditions are available to warfare commanders for visualization, and exploitation, of the battlespace. METOC data collection, fusion, and dissemination, combined with METOC community expertise and Network Centric (NC) warfare systems, is key to accomplishing this goal.

B. REQUIREMENTS FOR INTEGRATION

The Navy Integrated Tactical Environmental System (NITES) program is instrumental to the future of METOC support aboard surface combatants. NITES, managed by SPAWAR PMW-185, is developing METOC information systems to operate within the GCCS architecture. By incorporating interfaces to Moriah and hosting a METCAST client, the NITES workstation could serve as the primary focal point for METOC operations aboard a surface combatant. In the interim, an IT-21 SIPRNET workstation outfitted with the METCAST client or a JMCIS workstation with the Joint

METOC Segment (JMS) could provide this function. The long-term goal for the COE-compliant NITES workstations is a worthy endeavor, however, it is important to field a METOC support system in the near-term to support surface combatants. It is now possible, through METCAST, to display on one desktop multiple METOC products and data sets. A chart of the operating area could be overlaid with near real-time satellite imagery, observations, and gridded fields to give warfare commanders and ship commanding officers a true representation of the battlespace.

C. ADDITIONAL DATA SOURCES

Surface combatants generally possess a number of systems that monitor environmental data. For example, undersea warfare systems depend heavily on expendable bathythermographs (XBT) for vertical ocean temperature profiles that help predict sound propagation characteristics. Like weather observations, these profiles are coded into a plain text message and transmitted as message traffic. Systems such as the XBT recorder and Aegis Weather Radar could be linked to Moriah to provide a central acquisition and dissemination point for all environmental information leaving the ship. The consolidated transfer functionality of Moriah and ADNS should be fully exploited to retrieve as much METOC data from the ship as possible.

D. METCAST AND TACTICAL DECISION AIDS

METCAST is not limited to providing METOC support to the warfighter directly; it is feasible that METCAST could provide data fields for TDAs onboard the ship. EOTDA, AREPS, and VLSTRACK are but a few applications that can ingest these fields

to provide essential information for mission planning and execution. The TDAs would require proper network interfaces and use of the METCAST client for automated retrieval of current METOC information. The flexibility of METCAST makes the latter simple and would provide TDA developers with a much-improved process for data assimilation.

VII. CONCLUSIONS AND RECOMMENDATIONS

This demonstration has shown that the exchange of METOC information to and from surface combatants can be improved by deploying advanced environmental sensor suites, applying new data distribution technologies, and exploiting U.S. Navy communication systems. METCAST was shown to disseminate timely, relevant METOC information via ADNS to a surface combatant at sea. A prototype Moriah system was shown capable of transmitting high frequency, continuously acquired observations via ADNS to a shore METOC data collection point. It is apparent Moriah, METCAST, and ADNS offer a chance for METOC information to truly become a force multiplier. The following recommendations should streamline the integration of these systems aboard surface combatants:

A. DATA ACQUISITION

1. CNMOC

(a) Prior to Moriah installation, adopt ERM for the Ship's Weather Log.

(b) Once ERM has been adopted, eliminate manual completion and submission of CNMOC Form 3141/3 for ships equipped with Moriah.

(c) Upon Moriah installation, mandate reporting policy changes to include: hourly, or higher frequency, electronic submission of observations and elimination of weather guard ship for ships steaming in company.

2. Moriah

(a) Incorporate electronic transfer of observations via e-mail at least hourly with a feature to adjust frequency depending on environmental conditions or mission.

(b) Incorporate a Simple Network Management Protocol (SNMP) agent to provide a remote monitoring and control method in the event this protocol is authorized for use via ADNS to ships.

(c) Provide a data archive system capable of digitally storing measurements for extended periods of time in a format acceptable to the National Archives and Records Administration (NARA). Once ERM has been adopted, the archival system will already be in place.

(d) Provide interface and data collection for XBT systems initially, with the capability of adding more sensors in the future.

B. PRODUCT DISTRIBUTION

1. FNMOC/METCAST

(a) Explore multicasting features for transfer of common products to ships via ADNS and/or GBS.

(b) Improve compression techniques for METCAST products to lessen the burden on surface combatant networks.

(c) Develop METCAST management system for Regional Centers to allow control and monitoring of METOC information flow to assigned ships.

2. METOC Centers

(a) Actively manage METCAST subscriptions within AOR to ensure proper support is given to all ships.

(b) Train shipboard personnel in the proper use of Moriah and encourage feedback on performance.

(c) Continuously evaluate new products and methods that can exploit ADNS connectivity to surface combatants.

VIII. RECOMMENDATIONS FOR FOLLOW-ON WORK

A. DATA COLLECTION

The following data collection recommendations are made:

1. Conduct an operational test of Moriah under harsh conditions and evaluate sensor and processor performance characteristics.
2. Continuously explore Moriah sensor additions to improve shipboard measurements. For example, passive cloud sensing devices could further automate the observation process. Non-METOC sensors, such as chemical/biological agent detectors, could also be included within the Moriah framework to provide immediate notification of an attack. Moriah should easily accept additional sensors that might be required for specific missions.
3. Develop data assimilation methods that can ingest high frequency Moriah information for use in numerical models.

B. INFORMATION DISSEMINATION

The following information dissemination recommendations are made:

1. Pursue METCAST as a prime candidate for GBS. This will perhaps provide impetus to resolve interoperability issues and will serve to essentially remove size limitations on METOC products. The network connectivity may be sufficiently different that modifications to METCAST could be needed.

2. Explore next generation transport protocols for use within METCAST that may provide increased efficiency and security.
3. Increase interaction with surface combatants to continue testing of METCAST at sea. This will not only enhance METCAST performance, but also will make METCAST a visible, desirable product to the ship.

C. NETWORKING

The following recommendation for METOC networking are made:

1. METOC requirements of the DOD networks must be clearly defined. For example, the specific problem, whether policy or technical in nature, with the PRNOC firewall must be identified to determine the best method of transfer for Moriah data via ADNS. If the reason turns out to be a non-standard firewall configuration, the METOC requirement must be that DON networks comply with established standards. Stating a requirement for SNMP capability in order to remotely control and monitor Moriah systems may be a catalyst to employing SNMP over ADNS. METOC PKI requirements must be clearly stated to ensure proper authentication and security measures are available. The limitations of the networks should not define METOC information transfer methods; rather, METOC requirements should result in appropriate network configurations to support the transfer of information.

D. FLEET APPLICATIONS

The following recommendations are made regarding fleet applications:

1. Battlespace visualization of METOC information can be realized through Moriah observations, satellite imagery, numerical models, and in-situ and remote sensors. Significant research is required to create a visualization scheme that is robust enough to handle these multiple data sources and be easily viewed aboard a ship.
2. METOC products will need to undergo a design revolution to take advantage of this integrated METOC support capability. Fleet requirements should be aggressively identified to determine the exact format, content, and frequency for METOC products. As products are identified and distributed, evaluation by shipboard personnel is required to ensure the needs of the warfighter continue to be met.
3. Evaluations of JMCIS and METCAST integration are needed to determine compatibility and interoperability. JMCIS seems to be the logical choice for the METCAST client aboard ship; however, the role of NITES aboard a surface combatant must be clearly defined. Whether utilizing a desktop computer, JMCIS workstation, or NITES workstation, METCAST should be incorporated to ensure standardized transfer of METOC information and an operator should be faced with a single METOC product display interface.

APPENDIX A

PROTOTYPE MORIAH SENSOR PACKAGE

Campbell Scientific® CR10X Datalogger

R.M. Young® Wind Monitor - MA

Everest® Infrared Sea Surface Temperature Sensor Model 4000.4GL

AIR® Digital Barometer Model AIR-DB-1A

Rotronic® Air Temperature & Relative Humidity Probe Model MP-101A

Trimble® GPS Receiver Model SV6

Precision Navigation® Magnetic Compass Model TCM-2

APPENDIX B

PROTOTYPE MORIAH OBSERVATION FORMAT

Per Commander, Naval Meteorology and Oceanography Command (1996), WMO FM 13 SHIP synoptic code report format are to be used for naval surface ship observations. The applicable sections for the prototype Moriah system are described below. The Section 1 I_x field is assigned a value of six. This indicates the reporting station is automatic and is omitting weather date. This field will be used by FNMOC to identify Moriah automatic observations as opposed to the regular synoptic reports. Groups in Italics will not be reported by Moriah.

Section 0: BBXX DDDD $YYGGi_w$ $99L_aL_aL_a$ $Q_cL_oL_oL_oL_o$

Example: BBXX XNPS 30094 99365 71219

Description: XNPS(callsign) reporting at 0900Z on 30th day of month from position 36.5N 121.9W with measured wind speeds.

Section 1: $I_R\mathbf{I_x}Hvv$ Nddff (00fff) $1s_nTTT$ $2s_nT_dT_dT_d$ 4PPPP *5appp* *$7wwW_1W_2$* *$8N_hC_LC_MC_H$* 9GGgg

Example: 46/// /1815 10151 21016 40196 *7////* 90915

Description: Precipitation not observed, weather not observed from **automatic station,** cloud height not known, visibility not known. Winds from 180 at 15 knots. Air temp 15.1 degrees Celsius, Dewpoint –1.6 degrees Celsius, Pressure 1019.6 hPa, and actual time of observation 0915Z.

Section 2: $222D_sv_s$ $0s_sT_wT_wT_w$ $2P_wP_wH_wH_w$ $3d_{w1}d_{w1}d_{w2}d_{w2}$ $4P_{w1}P_{w1}H_{w1}H_{w1}$ $5P_{w2}P_{w2}H_{w2}H_{w2}$ $6I_sE_sE_sR_s$ $8S_wT_bT_bT_b$ ICE +Plain language or ICE $c_IS_Ib_ID_Iz_I$

Example: 222// 06185 85135

Description: SST is 18.5 degrees Celsius from sensor other than hull, intake, or bucket (i.e. IR), wet-bulb temperature computed as 13.5 degrees Celsius.

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